

Automated Programmable Scanning Plane Orientation of CERES Instruments

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Abstract – CERES scanners on board the Terra and Aqua satellites are used to collect Earth’s radiation budget data. When the instruments operate in a special, programmable azimuth plane scan (PAPS) mode, the data collection can meet additional objectives. Two such cases are discussed in this paper. In the first case, a scanning plane orientation is parallel to the solar plane, and in the other, the orientation coincides with a geostationary satellite viewing geometry. In both cases, a scanner stays in a special mode for about 30 minutes per orbit. Since this requires a large amount of commands, automation of the command upload is highly desirable, and its implementation is also discussed in this paper.

I. INTRODUCTION

A Clouds and Earth Radiant Energy System (CERES) instrument is a scanning thermistor bolometer designed to measure reflected solar radiation and outgoing longwave radiation from the Earth for radiation budget studies (Wielicki, 1995). Since 1998, CERES instruments have played an important role in the Earth Observing System (EOS) mission with the launch of the Proto Flight Model (PFM) on board the TRMM satellite. Two CERES instruments, Flight Model 1 and 2 (FM1 and FM2), have been operating on board the Terra satellite since the beginning of 2000. In May, 2002, two additional CERES instruments (FM3 and FM4) were put in service on board the Aqua satellite. Since their launch, CERES instruments have been used in various field campaigns to provide increased coverage of selected Earth targets to meet research goals. An overview of these campaigns is provided by Szewczyk and Priestley (2003).

CERES instruments have been also involved in two additional special campaigns whose objectives go beyond simple observations of Earth targets. One of them is extensive scanning in the principal (solar) plane (PPS) with the objective of building refined angular distribution models or ADMs. The other one is scanning in the viewing geometry of a geostationary, the Meteosat Second Generation (MSG), satellite with the objective of validating radiation measurements of a

Geostationary Earth Radiation Budget (GERB) instrument (Smith et al. 2003). Both campaigns, the PPS and the CERES/GERB, are briefly described in this paper.

Meeting scanning constraints of both campaigns requires a large amount of commands to maintain the proper scanner orientation in an orbit. There are several orbits per day when a CERES instrument executes special scanning; and in addition, a campaign may be a few weeks long. Therefore, another objective of this paper is to present an automated process of command generating and uploading that has been utilized in both campaigns. A focus of this presentation is on an overview of CERES participation in both campaigns rather than on science data analysis.

II. CERES SCANNING MODES

A CERES scanner has three channels: total (0.3-100 μm), shortwave (0.3-5 μm), and a longwave window (8-12 μm) which measure different parts of the spectrum. A full sweep lasts 6.6 sec., and with a sampling rate of 100 sec^{-1} , it produces 660 samples. There are two basic operational modes of a scanner, namely (i) a cross-track (XT) mode where the scanning plane is perpendicular to the satellite velocity vector, and (ii) a rotational azimuth plane scan (RAPS) mode where the scanning plane orientation changes at a constant rate. The third operational mode, the programmable azimuth plane scan, has been introduced to meet special requirements of the scanning plane orientation.

When in the PAPS mode, a scanner head is rotated in the azimuth plane in a step-wise manner to maintain a prescribed orientation of the scanning plane. During each step the instrument relative azimuth is kept constant, but the duration of each step changes with the satellite position in an orbit. Once the whole command sequence is finished, an instrument goes back to one of the normal modes.

Putting a CERES instrument in the PAPS mode for a special coverage is intended as a free service to the

science community, and it can be requested on the CERES website:
<http://asd-www.larc.nasa.gov/PAPS/cgi-bin/rygar.cgi>.

III. AUTOMATED COMMAND PROCESS

Automated planning tools that make predictions for the programmable azimuth plane scan mode, or for a CERES instrument relative azimuth and also for command uploads reside on the CERES website for special operations:

http://asd-www.larc.nasa.gov/PAPS/CERES_PAPS.html

The instrument head orientation for the PAPS mode is calculated based on a satellite ground track prediction file available in advance for seven days. A satellite location is given in one-minute intervals in this file, and it is interpolated to 6.6 sec., or the duration of a single scan. A refined geolocation of a satellite and requirements for the scanning geometry are then used to produce seven daily files that contain information about the time and relative azimuth setting for each scan. Since there is a 48-hour turnaround for commanding a CERES instrument into the PAPS mode, only predictions following the second day are of practical value. The whole process of downloading a ground track file, executing prediction programs and updating web pages is fully automated, and it does not require any human intervention. However, daily command sequences had to be manually keyed in for uploads to a satellite from a ground station.

The PAPS mode employed in the PPS and CERES/GERB campaigns requires about sixty commands per orbit to maintain the proper scanning plane orientation. With 3-4 orbits per day requiring the PAPS mode, the total number of commands to be keyed daily has justified an additional effort to further automate the process. As a result of that, a new processing step has been added to the website in which command sequence files are also generated automatically. The CERES Operation Team uses these files in a newly devised procedure to speed up and facilitate command uploads. Since this step is slightly different for the Terra and Aqua satellites, it is further described in the following subsections.

IV. SCANNING IN THE PRINCIPAL PLANE

A. Objectives

The objective of the Principal Plane Scanning (PPS) campaign is to increase sampling in the principal, or solar, plane. In this plane, the anisotropy of Earth scenes is highly variable, changing dramatically depending on the physical properties of the medium. Examples of scenes with intriguing angular signatures

in the principal plane include clear ocean due to sun-glints, clear land due to "hot spots" and shadows, overcast clouds due to rainbow and glory features and the sensitivity to particle size and shape, and broken clouds due to 3-D effects.

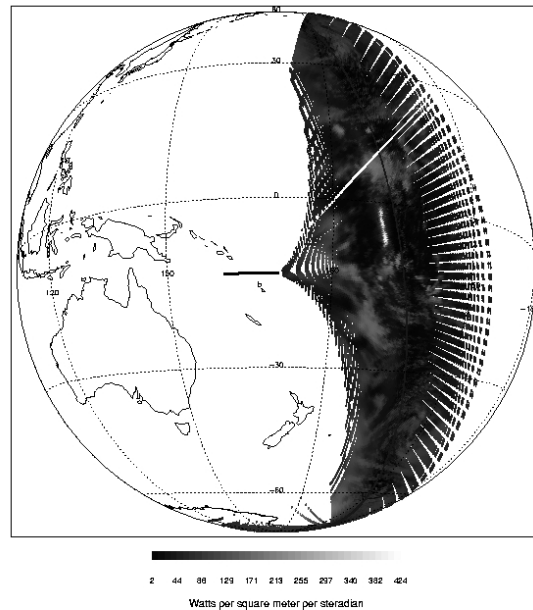


Figure 1. Shortwave radiance over the Pacific ocean at 00:22GMT on October 19, 2003. A very bright spot just south from equator may indicate a sun glint.

CERES science products use an empirical ADM to infer top-of-atmosphere (TOA) radiative fluxes from instantaneous measured radiances (Loeb, 2001). To develop ADMs from CERES radiances, measurements are needed for all combinations of instrument viewing zenith angle (VZA) and relative with respect to the Sun azimuth angle (RAZ) in all observed conditions. Because ADMs are so much more sensitive to the detailed physical properties of the scene (i.e. surface and cloud conditions) in the principal plane than they are in other viewing geometries, it is necessary to dedicate scanning to increase sampling in the principal plane.

B. PPS campaign

The PAPS mode can address the need for increased sampling in the principal plane. A CERES instrument, FM3, aboard the Aqua satellite was put in this mode for more than two weeks between October 20 and November 5, 2003 to collect radiances in that plane. Since an additional requirement for this campaign was to collect "clear sky over ocean" data, only these orbits

were selected when the satellite was flying over the Pacific and Atlantic oceans. This resulted in three to four orbits per day in which the PAPS mode was used. It is worth mentioning that the scanning in the principal plane is an on-going CERES instrument activity as data for other scene types and cloud conditions are also needed.

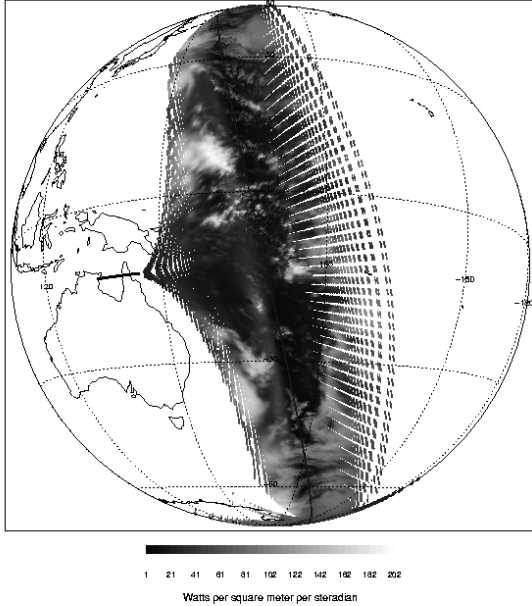


Figure 2. Shortwave radiance over the Pacific ocean at 02:02GMT on October 29, 2003. Bright spots indicate clouds.

C. Stored Command Sequences (SCSs)

The Terra and Aqua satellites are in sun-synchronous, polar orbits with equatorial crossings at 10:30AM (descending) and 1:30PM (ascending), respectively. Their orbits are inclined at 81.8° and 98.2° at the altitude of 707 km. Since each orbit is fixed with respect to the sun, the principal plane orientation is a function of the satellite latitude and the sun declination angle. During the campaign, the sun declination angle was in the range of $[-10.4^\circ -15.7^\circ]$, and it changed slightly daily. To take advantage of a small change in the principal plane orientation, a SCS was generated for the sun declination angle of -13° . This SCS was used for the whole duration of the campaign. The resulting discrepancy between the principal and scanning plane was never greater than 3° , and its average value was less than 0.1° . Such an accuracy is deemed satisfactory as the shortwave reflectance remains virtually constant within 5° . The duration of the PAPS mode is restricted by a solar avoidance angle (SAVA). Since this angle was set to 18° , the command sequence lasted 38

minutes or about 350 scans per orbit. This command sequence was stored aboard the Aqua satellite several weeks before the start of the campaign as a command macro. Its execution during the campaign only required an upload of a time when to start the sequence as its last command was a return of the instrument head to the cross-track mode. The start time was predicted daily and was available from the website. With this command macro (SCS) in place, the daily routine of the CERES Operation Team was reduced to adding a few commands that would specify when to start each SCS.

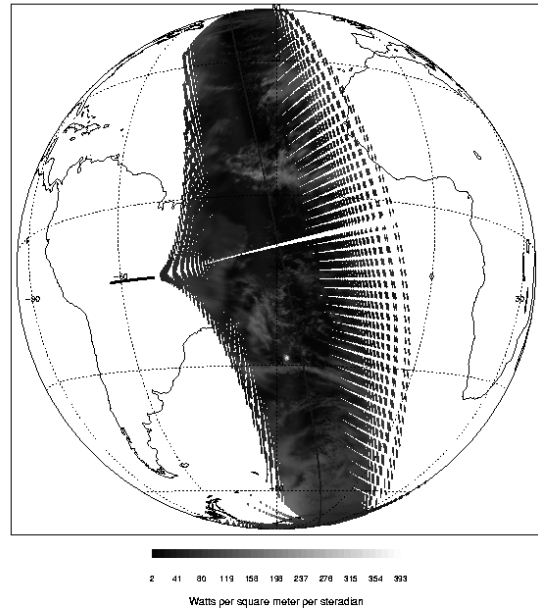


Figure 3. Shortwave radiance over the Atlantic ocean; virtually clear sky conditions.

D. PPS scanning pattern

There are three plots in this paper that show the typical, daily scanning pattern during the campaign. These plots are generated using the view_hdf software, developed by SAIC over the last few years to address the need for a GUI-based software to efficiently read and visualize an HDF file content (Lee, Spence, 2002).

The plots show shortwave radiances made for three daytime passes of the Aqua satellite over the Pacific and Atlantic oceans, at 00:22GMT, 02:02GMT, and 15:14GMT. Each pass lasts about 38 min. A satellite ground track and the Sun locations are also shown.

V. SCANNING IN THE GERB GEOMETRY

A. Objectives

A GERB instrument is the first broadband radiometer on board the MSG spacecraft placed at 10.5°W in August, 2002. From its position, the GERB provides measurements of reflected solar radiances and outgoing longwave radiances over the visible portion of the Earth. It takes a snapshot of the energy budget every 15 minutes at a resolution of about 0.5° in latitude and longitude directions. The instrument consists of an array of 256 detectors providing 256 total and shortwave channels (Harries et al., 2000). More information about the GERB experiment can be found: <http://www.sp.ph.ic.ac.uk/gerb>.

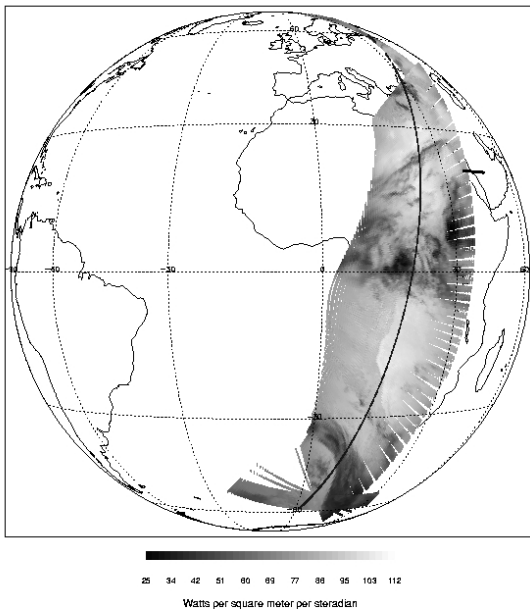


Figure 4. The first pass of the Terra over the GERB visible portion of the Earth at 09:04 GMT on May 24, 2003; longwave radiance is shown on this plot.

There is a consistent, two decades long Earth radiation budget data set established based on measurements obtained from various instruments. By carefully validating instruments with respect to each other, such a set can be used for long-term climate studies. CERES instrument measurements have been part of this dataset since 1998. The GERB instrument measurements need to become a part of this set as well, as they offer unprecedented information about the diurnal cycle of heating and cooling of the Earth. In order to include its measurements, however, GERB radiances must be validated for their consistency with CERES. The main objective of CERES/GERB campaign is such a validation attempt.

Shortwave radiances from a scene are highly anisotropic as they change with a viewing zenith angle (VZA) and an azimuth angle relative to the Sun. In order to make a valid comparison of radiance measurements by two different instruments, it is important to match their viewing geometries at a given time instance. In addition to this spatial and temporal

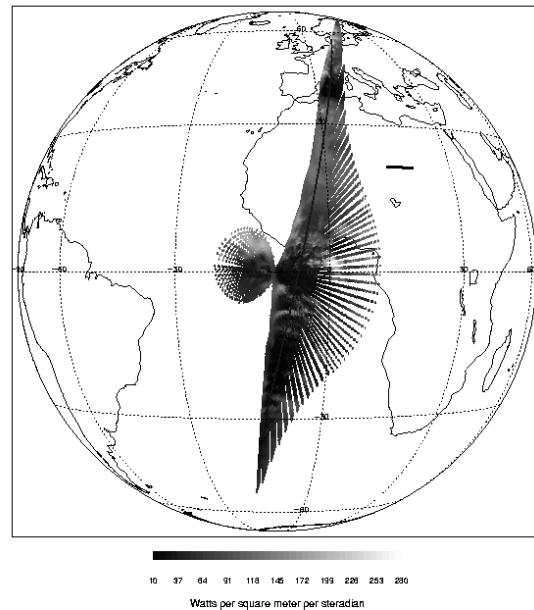


Figure 5. The second pass of the Terra over the GERB visible portion of the Earth at 10:39 GMT on May 24, 2003; shortwave radiance is shown on this plot.

alignment, selecting homogenous energy sources to be measured is required for valid comparison. Despite the fact that a LEO and a GEO satellites Earth viewing geometries are quite different, it is possible to match them utilizing a unique feature of the CERES PAPS mode. This is accomplished by rotating the CERES scanning plane to align it with the GERB relative azimuth as the satellite flies over the GERB instrument visible portion of the Earth. In addition, CERES VZA is matched with the GERB elevation angle. Such an alignment of angles is necessary to avoid using a bidirectional reflectance function (BRDF) twice on comparing CERES/GERB radiances. It is clear that errors in the BRDFs would go straight into the inter-comparison of the instruments. There are no ideal energy sources to be measured by both instruments. Therefore, collecting a large amount of data for different scene types and averaging is the only viable alternative for valid comparison. The PAPS mode

addresses this problem as well by allowing CERES to collect hundreds of samples per each orbit.

B. GERB campaign

A CERES instrument (FM2) aboard the Terra satellite participated in the CERES/GERB campaign from May 24 to June 6, 2003. During these 14 days, FM2 scanned in the PAPS mode in about 60 orbits. Each orbit contained about 200 dedicated scans matching the GERB geometry. The amount of data collected was sufficient to make a preliminary assessment of the consistency between CERES and GERB radiances.

C. One Day Sequences (ODSs)

Matching the GERB relative azimuth requires up to 50 commands per orbit for a total of about 200 commands per day. In an attempt to reduce the CERES Operation Team workload, a new approach to command upload

year underscores the importance of introducing this automated link to the whole process.

D. CERES/GERB scanning pattern

There are four plots in this paper that show the typical, daily scanning pattern during the campaign. The plots are made for four daytime passes of the Terra satellite over the visible GERB portion of the Earth. They start with a morning pass far East at 9:04GMT, and then at 10:39GMT, 12:18GMT, and 13:59GMT. Each pass lasts about 25 min. A satellite ground track and the Sun locations are also shown. It is worth noting that each scan is entirely contained within the GERB field of view. An example of the GERB images is also shown.

V. CLOSING REMARKS

The paper demonstrates the flexibility and efficiency of CERES instruments and their operation team. By automating important steps of the command process, it is shown that even extensive special coverage requiring many days of the programmable azimuth plane scanning is available.

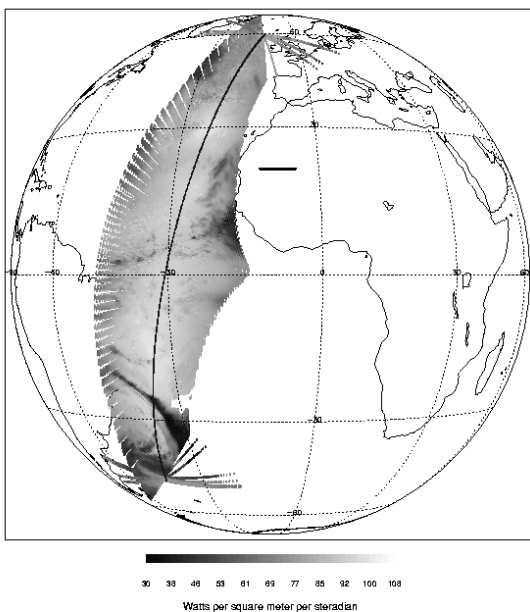


Figure 6. The third pass of the Terra over the GERB visible portion of the Earth at 12:18GMT on May 24, 2003; longwave radiance is shown on this plot

was devised for this campaign. In this approach, a command sequence, referred to as One Day Sequence (ODS), is generated automatically on the CERES website. This sequence format adheres to strict formatting guidelines required by the command upload protocol. ODS is generated daily and via secure transfers is uploaded to the Terra satellite from the West Sands ground station. The fact that the CERES/GERB campaign needs to be repeated twice a

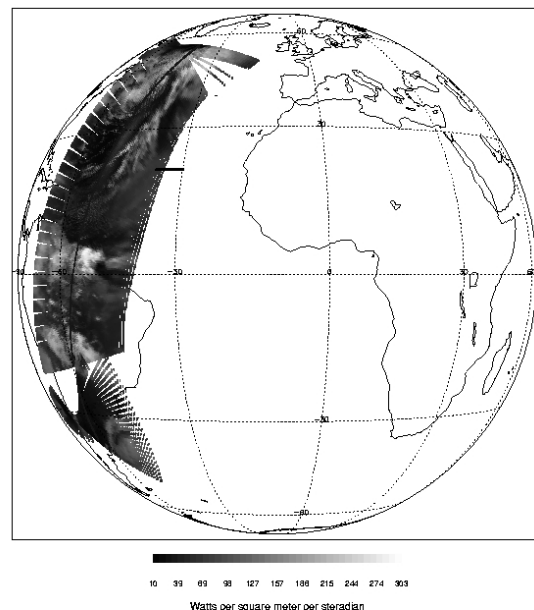


Figure 7. The fourth pass of the Terra over the GERB visible portion of the Earth at 13:59GMT on May 24, 2003; shortwave radiance is shown on this plot.

The instruments have been extensively used in various other research projects, and a full list of their activities since launches can be found:

<http://asd-www.larc.nasa.gov/ceres/ASDCeres.html>.

Readers are encouraged to check the listed websites for information about the impact of CERES data on the results and outcome of specific experiments described in this paper.

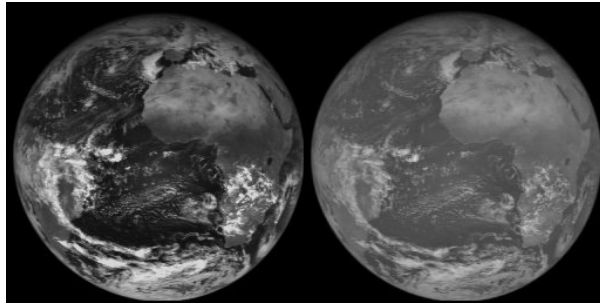


Figure 8. Shortwave and longwave GERB radiances are shown on this plot taken at 13:55GMT on May 24, 2003.

VI. REFERENCES

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